

METHODS AND SYSTEMS FOR ESTIMATING RETICLE BIAS STATES

CLAIM OF PRIORITY

[0001] This application claims priority to U.S.S.N. 60/453,774, entitled "Method to Automate State Estimates of Reticle Offsets in Microlithography Semiconductor Manufacturing," filed on March 11, 2003, naming Joseph C. Pellegrini and David Crow as inventors, the contents of which are herein incorporated by reference in their entirety.

BACKGROUND

(1) Field

[0001] The disclosed methods and systems relate generally to control techniques, and more particularly to control systems for materials manufacturing processes such as semiconductor manufacturing processes.

(2) Description of Relevant Art

[0002] Lithography is a process used in semiconductor manufacturing to transfer a circuit pattern from a photomask or reticle to a semiconductor wafer, or more specifically, to transfer the photomask pattern to a layer of resist that has been deposited on the wafer surface, where the resist is sensitive to irradiation. Different types of lithography can be based on the wavelength of the radiation used to expose the resist. For example, photolithography, otherwise known as optical lithography, uses ultraviolet (UV) radiation and a corresponding UV-sensitive resist. Ion beam lithography uses a resist sensitive to an ion beam, electron beam lithography uses a resist film sensitive to a scanning beam of electrons to deposit energy therein, and X-ray lithography uses a resist sensitive to X-rays.

[0003] Photolithography employs a photomask that can be understood to be a quartz plate that is transparent to UV radiation and includes a master copy of an integrated circuit that is often

1 a microscopic integrated circuit. The photomask can be used to block resist exposure to select
2 areas using chrome opaque areas.

3 **[0004]** A stepper is a resist exposure tool used in many photolithography systems to expose
4 part of the wafer or resist in a given exposure. Systems employing a stepper can require a “step-
5 and-repeat” process to expose the entire wafer as desired. A scanner is another type of resist
6 exposure tool used in photolithography systems to expose part of the wafer or resist in a given
7 exposure. Systems employing a scanner can require a “step-and-scan” process to expose the
8 entire wafer as desired. In the aforementioned systems, overlay can be understood as the
9 superposition of the pattern on the mask to a reference pattern previously created on the wafer
10 surface. Related to overlay is alignment, which can be understood to be including positioning, or
11 aligning, the mask or reticle relative to markers or targets on the wafer, prior to the exposure.
12 Accordingly, to achieve proper exposure, overlay and alignment, among other parameters, must
13 be properly controlled.

14 **[0005]** As the demand for smaller and more complex circuits increases, there is similarly
15 increased demand for monitoring and hence improving overlay and alignment errors.
16 Contributing to such errors can be the x-alignment of the wafer, the y-alignment of the wafer, the
17 scale error or ratio of desired to actual stage movement in the x and y directions, the rotational
18 error of the wafer, the reticle magnification error, and the reticle rotation error, among others.

19 **[0006]** To reduce these errors, it may be desirable to estimate reticle bias states related to
20 overlay and critical dimension.

21 SUMMARY

23 **[0007]** Disclosed are methods and systems for estimating a reticle bias state for a process
24 system, that include computing a difference between control data provided to the process system
25 and error data based on at least one output of the process system, and estimating the reticle bias
26 state based on weighted measures associated with the control data, where the weighted measures
27 are based on the number of data points included in the difference. The weighted measures can
28 include normalized weighted measures, where such weighted measures can be based on the

1 square root of the number of data points included in the difference. In some embodiments, the
2 weighted measures are multiplied by a constant factor.

3 **[0008]** As disclosed, the methods and systems can also include normalizing the reticle bias
4 state estimate, where the normalizing can be based on a sum of the weighted measures.

5 **[0009]** In some embodiments, the reticle bias state estimate can be associated with a quality
6 factor. The quality factor can be based on a sum of the squares of the weighted measures. In an
7 embodiment, the quality factor can be based on a square root of a sum of the squares of the
8 weighted measures. The associated quality factor can be compared with at least one threshold.
9 In one embodiment, the threshold(s) can include a use threshold to determine whether to provide
10 the reticle bias state estimate to the process system, and/or a stop-learning threshold to determine
11 whether to continue updating the reticle bias state estimate.

12 **[0010]** The disclosed methods and systems can include comparing the associated quality
13 factor with a previously computed quality factor associated with a previously computed reticle
14 bias state estimate, where the previously computed reticle bias state estimate corresponds to the
15 same reticle as the associated quality factor. Based on the comparing, the previously computed
16 quality factor associated reticle bias state estimate may be updated. Accordingly, the methods
17 and systems can include performing a second comparing between the associated quality factor
18 and at least one threshold, where the threshold(s) can include a use threshold to determine
19 whether to provide the reticle bias state estimate to the process system, and/or a stop-learning
20 threshold to determine whether to continue updating the reticle bias state estimate.

21 **[0011]** Also disclosed are methods and systems that for updating and/or computing a reticle
22 bias state estimate. The methods and systems can include associating a reticle bias state estimate
23 with a first quality factor, computing at least one weighted measure based on a number of data
24 elements associated with the reticle, using the at least one weighted measure to provide a
25 computed reticle bias state estimate and an associated computed quality factor, and, comparing
26 the computed quality factor with the first quality factor to determine whether to update the reticle
27 bias state estimate with the computed reticle bias state estimate.

1 **[0012]** The comparing can include comparing the computed reticle bias state estimate to a
2 use threshold to determine whether to use the computed reticle bias state estimate. The
3 comparing can also include comparing the computed reticle bias state estimate to a stop-learning
4 threshold. The comparing can include updating the first quality factor with the computed quality
5 factor and updating the reticle bias state estimate with the computed reticle bias state estimate,
6 when the computed quality factor exceeds the first quality factor.

7 **[0013]** The disclosed methods and systems can include setting the first quality factor to a
8 value to cause at least one of: an update to the reticle bias state estimate, no update to the reticle
9 bias state estimate, and no use of the reticle bias state estimate.

10 **[0014]** In one embodiment, the weighted measure can be based on the square root of the
11 number of data elements associated with the reticle. Accordingly, computing the weighted
12 measure(s) can include computing the weighted measure(s) for each of different queries
13 associated with the reticle, and, normalizing the weighted measure(s) to provide at least one
14 normalized weighted measure.

15 **[0015]** The methods and systems can include using the weighted measure(s) such that a
16 largest normalized weighted measure is identified, and, based on the largest normalized weighted
17 measure, a computed reticle bias state estimate is generated.

18 **[0016]** In one embodiment, the methods and systems can include computing a quality factor
19 based on a sum of the squares of the weighted measure(s).

20 **[0017]** It can be understood that the reticle bias state estimate can be provided to a process
21 system that can include a lithography system and/or a microlithography system. Accordingly, the
22 disclosed methods and systems can further include measuring at least one process system error in
23 providing a wafer to an overlay metrology system. Measuring the process system error can
24 include, for example, providing measurements associated with at least one of: an x-translation, a
25 y-translation, an x-scaling, a y-scaling, a wafer rotation, , a non-orthogonality, a reticle
26 magnification, an asymmetric reticle magnification, a reticle rotation, and an asymmetric reticle
27 rotation.

1 **[0018]** Other objects and advantages will become apparent hereinafter in view of the
2 specification and drawings.

3
4 **BRIEF DESCRIPTION OF THE DRAWINGS**

5 **[0019]** FIG. 1 illustrates a control system using feedback;
6 FIG. 2 is an exemplary control system having feedforward and feedback;
7 FIG. 3 presents another control system having feedforward and feedback; and,
8 FIG. 4 is an example logic flow diagram for updating and/or selecting a reticle bias
9 state estimate based on an associated quality factor.

10
11 **DESCRIPTION**

12 **[0020]** To provide an overall understanding, certain illustrative embodiments will now be
13 described; however, it will be understood by one of ordinary skill in the art that the systems and
14 methods described herein can be adapted and modified to provide systems and methods for other
15 suitable applications and that other additions and modifications can be made without departing
16 from the scope of the systems and methods described herein.

17 **[0021]** Unless otherwise specified, the illustrated embodiments can be understood as
18 providing exemplary features of varying detail of certain embodiments, and therefore, unless
19 otherwise specified, features, components, modules, and/or aspects of the illustrations can be
20 otherwise combined, separated, interchanged, and/or rearranged without departing from the
21 disclosed systems or methods. Additionally, the shapes and sizes of components are also
22 exemplary and unless otherwise specified, can be altered without affecting the disclosed systems
23 or methods.

24 **[0022]** For the disclosed methods and systems, references to a reticle can include a mask and
25 a photomask, and variations thereof. Further, references to a database can be understood to be a
26 memory that can be capable of associating memory elements.

27 **[0023]** References herein to controlling a reticle-induced error(s) in a process system can be
28 understood to include controlling errors in a process system that may physically employ or

otherwise include a reticle, and/or process systems that may be affected by reticle characteristics (e.g., errors), regardless of whether a reticle is employed or actually physically included in the process system. The disclosed process systems can thus be understood to be associated with at least one reticle, where the such reticle(s) can be further associated with at least one reticle error. Accordingly, references herein to “the process system reticle,” etc., can be understood to be the one or more reticles whose errors can affect the process system, regardless of whether the reticle(s) may be physically present in the process system.

[0024] Figure 1 provides one illustrative depiction of a system **10** that includes a process system that can be affected by reticle-induced errors, in an embodiment that can be associated with semiconductor manufacturing. It can thus be understood that the general concepts discussed relative to Figure can be applicable to the systems and methods of Figures 2 and 3, for example, although such concepts may not otherwise be illustrated therein, and unless such concepts are otherwise controverted and/or disclaimed with respect to such other Figures. In accordance with Figure 1, materials such as semiconductor wafers can be input to a process system **12** and hence to a measurement system **14**. The illustrated process system **12** can be, for example, a system that performs lithography, chemical mechanical polish (CMP), diffusion, thin film, metal deposition, ion implantation, etching, or another process system. The illustrated measurement system **14** can be, for example, a metrology system such as an overlay measurement system or tool, a critical dimension measurement tool, a thickness measurement tool, a film reflectivity measurement tool, or another measurement tool or system. Accordingly, for one such embodiment based on Figure 1, semiconductor wafers can be presented to a photolithography system **12** and thereafter to an overlay measurement tool **14** that provides measurements based on the processed wafers.

[0025] As shown in Figure 1, raw data from the measurement system **14** can be provided for processing and/or analysis **16**, where the raw data can include measurements from the measurement system **14**, configuration data (e.g., component identifiers, system identifiers, etc.) based on the process system **12** and/or the measurement system **14**, and other data (e.g., date, time, etc.). For a system according to Figure 1, a data processing/analysis module **16** can be

1 based on the process system 12 such that the output of the data processing/analysis module 16
2 can be configured to provide data in a form that can be used by and/or is otherwise compatible
3 with the process system 12. In some systems, for example, the data processing/analysis module
4 16 can include modules for modeling and/or otherwise estimating at least some components
5 and/or processes of the process system 12. In an illustrative embodiment where the process
6 system 12 can be a lithography system and the measurement system 14 can be an overlay
7 measurement system, the data processing/analysis module 16 can include, for example, least
8 square regression models for components of the lithography system 12. Those with ordinary skill
9 in the art will recognize that such models and/or estimation modules are not limited to least
10 square regression models, and other estimation and/or modeling techniques can be used without
11 departing from the scope of the disclosed methods and systems.

12 **[0026]** In the illustrated embodiments, the data processing/analysis module 16 can provide
13 error signals and/or data as output. Accordingly, in an embodiment based on the aforementioned
14 lithography system, the data processing/analysis module 16 can provide error data that can
15 include errors based on, for example, x-translation, y-translation, x-scaling, y-scaling, wafer
16 rotation, grid non-orthogonality, reticle magnification, reticle rotation, and/or others, where those
17 of ordinary skill in the art will recognize that such error signals are merely for illustration and not
18 limitation, and some embodiments may include fewer and/or more error data, where the error
19 data can be in either analog and/or digital form. Unless otherwise provided herein, the data
20 throughout the disclosed embodiments and the disclosed methods and systems can be understood
21 to be in either digital or analog form without departing from the scope of the disclosed methods
22 and systems.

23 **[0027]** Although the data processing/analysis module 16 is not limited to providing error data
24 as output, for the discussion herein, such module's output can be referred to collectively as error
25 data, where such error data can also include data based on the configuration of the process system
26 12 and/or the measurement system 14, and/or other data. To facilitate an understanding of
27 systems and methods according to Figure 1, the error data can be understood to include an error

vector that can have at least one row and at least one column, where the size of the error vector can be based on the process system **12** and/or the measurement system **14**.

[0028] Systems and methods according to Figure 1 can also include a filter **18** that can operate on data based on the data processing/analysis output, and filter such data based on fixed and/or variable criteria. A system administrator, user, or another can establish or otherwise provide the filter criteria. In one illustrative system, the filter **18** can be based on user-defined rules that can qualify the filter input data to determine whether such filter input data should be employed for controlling and/or otherwise characterizing the process system **12**. The filter **18** may be viewed as providing a condition for utilizing the input data to characterize the process system **12**. For example, the filter **18** can distinguish data based on a number of successfully measured raw data points provided by the measurement system **14**, where the number can be user-specified in some embodiments. In one embodiment, if a specified number of successfully measured raw data points are not provided, the data can be distinguished as inappropriate for feedback to the process system **12** in accordance with a system based on Figure 1. Additionally and/or optionally, the filter **18** can route or otherwise distinguish or classify data based on data markers, flags, or other data that can indicate that the data input to the filter **18** can be ignored or may otherwise be inappropriate for feedback to the process system **12**. In one example, the error data can be marked or otherwise designated as being associated with a special event. In some embodiments, the filter **18** can include validation rules that can be applied to the data input to the filter **18**. In illustrative systems, the filter **18** can include statistical and/or other filtering techniques that can include, for example, classification techniques such as Bayesian classifiers and neural networks.

[0029] Systems and methods according to Figure 1 can also include a gain amplifier **20** that can be a variable gain amplifier. A gain table **22** can accordingly provide stored gain values that adjust data based on the filtered error vector to compensate for scaling, sign differences, and other process system **12** and/or measurement system **14** characteristics. A gain amplifier output, Eg, can be provided to a vector generation module **24** that can provide a difference between: (a) data representing actual control data (offsets, commands, etc.), A, provided to the process system

12; and, (b) the gain amplifier output, E_g . The difference vector $I=A-E_g$, can be understood to represent an actual control to the process system 12, less the errors generated by such control. Those of ordinary skill in the art will recognize that the delay in providing the actual control, A , and receiving the error vectors, E_g , can be on the order of seconds, minutes, hours, or days.

[0030] Data based on the difference vector I can be provided to a correlator module 26 that identifies and processes data from events having similar process system 12 characteristics. For example, for a given process system 12, events having similar characteristics can include events that are processed using similar configurations of the process system 12 and/or measurement system 14. In an embodiment where the process system 12 can be a lithography system and the measurement system 14 can be an overlay measurement system, for example, characteristics can include a lithography system identifier, a reticle identifier, a routing identifier (e.g., material used in processing), an operation identifier (e.g., operation being performed), a process level identifier (e.g., stage of processing), an exposure tool identifier, and/or a part number, although such examples are provided for illustration and not limitation, and fewer and/or more system characteristics can be used to characterize an event. An event database 28 or other memory component can thus include historical measurement data that can be provided by the measurement process 14 and thereafter be accessed by or otherwise integrated with the correlator module 26 to allow a feedback control and/or command vector, C_{FB} , to be computed based on a historical evaluation of similar process system 12 and/or measurement system 14 configurations. In some embodiments, C_{FB} can provide incremental control/commands to the process system 12, while in some embodiments, C_{FB} can provide an absolute control/command to the process system 12. Those of ordinary skill in the art will recognize that in the illustrated embodiment, the dimension of C_{FB} can be based on or be the same as E_g , as the commands provided by C_{FB} can be associated with the process system components for which error data can be obtained.

[0031] In some embodiments, event database data can be associated and/or correlated to facilitate queries of the event database 28. In the illustrated system, the event database 28 can associate actual command data, A , and gain amplifier outputs, E_g , with “correlation keys” that represent process system characteristics, and can otherwise be understood to be query and/or

1 index terms. Accordingly, as shown in Figure 1, the correlator module **26** can provide a
2 command vector, C_{FB} , to the process system **12**, where C_{FB} can be based on a query of the event
3 database **28** and associated I vector data that can be based on the query. The event database
4 query can otherwise be understood to be a “feedback request,” and as provided herein, can be
5 based on correlation keys or process system characteristics.

6 **[0032]** One of ordinary skill will recognize that although not explicitly indicated in the
7 illustrated embodiments, the event database **28** can include actual command data A, and gain
8 amplifier outputs E_g that may otherwise be understood as errors. Accordingly, an ideal vector, or
9 difference vector, I, can be recreated from respective A and E_g data.

10 **[0033]** In one embodiment, the command vector, C_{FB} , can be based on a weighted moving
11 average (“WMA”) of historical difference vectors (e.g., “I vectors”) that can be further based on
12 similar process system characteristics and included in the event database **28**. The weighted
13 moving average can also be based on a user-specified time-period that can specify a time over
14 which the I vector data can be collected for incorporation into, for example, a weighted moving
15 average. The weighted moving average can be based on fixed and/or variable weights that can be
16 specified by a user, for example. As provided previously herein, in some embodiments, the
17 command vector can be of the same dimension as the gain amplifier output, E_g , and can include
18 similar vector elements. For example, in accordance with a process system **12** that includes a
19 lithography system or tool, a command vector may include at least one control associated with at
20 least one of an x-translation error, a y-translation error, an x-scaling error, a y-scaling error, a
21 wafer rotation error, a non-orthogonality error, an asymmetric magnification error, an asymmetry
22 rotation error, a reticle rotation error, a reticle magnification error, a critical dimension (CD)
23 linewidth bias, a dose bias, a reticle density, a mask density, a frame-to-frame alignment, a
24 distance from optical center to frame center, an alignment mark line size, an alignment mark
25 density, and an alignment mark duty cycle, although such examples are provided for illustration
26 and not limitation.

27 **[0034]** The illustrated event database **28** can employ a commercially available database (e.g.,
28 SQL, Informix, Oracle, Access, etc.) or another system for associating data and allowing such

1 associated data to be queried and/or retrieved according to the methods and systems disclosed
2 herein. In an embodiment where the process system **12** includes a lithography system, the event
3 database **28** can be arranged to associate data based on, for example, process system
4 characteristics and/or other correlation keys that can include a technology identifier (e.g., type of
5 processor, operating system, etc.), a reticle identifier, a route identifier, an operation identifier, a
6 process level identifier, an exposure tool identifier, and/or a part number, although such
7 examples are merely illustrative, and some embodiments can use fewer and/or more identifiers or
8 process system characteristics.

9 **[0035]** The correlator module **26** can thus also include or otherwise provide for rules for
10 querying the event database **28**. In an embodiment, a user and/or system administrator can
11 provide default query rules that can be modified using, for example, an interface such as a
12 graphical user interface (GUI). For example, a user may provide the correlator module **26** with a
13 hierarchy of query criteria and filter criteria such that one or more correlation keys or query
14 criteria can be eliminated from the query or otherwise presented as a wildcard in the query if the
15 filtered query results are not sufficient. Accordingly, query results can be filtered based on
16 default and/or user-specified criteria that can include, for example, a minimum number of query
17 results, a maximum number of query results, a time period within which the data may have been
18 collected, and/or a type of weighting average to apply. In an embodiment, if the filtered query
19 results are inadequate to allow for a computation of the control/command vector, C_{FB} , the
20 disclosed methods and systems can allow for a wildcarding of system parameters based on a
21 user's hierarchical wildcarding configuration. Such a system can thus perform several feedback
22 requests or database queries and filterings before obtaining query results sufficient for computing
23 C_{FB} .

24 **[0036]** In one example, a user may query the event database **28** based on process system
25 characteristics that include a technology identifier (ID), a routing identifier (ID), a process level
26 identifier (ID), an operation identifier (ID), a device (or part number) identifier (ID), a reticle
27 identifier (ID), an exposure tool identifier (ID), and/or another process system characteristic. The
28 query may further specify or it may otherwise be known that data satisfying such process system

characteristics must be within a time period in the last M weeks, and further, at least N data points must be collected for a valid retrieval. Because the criteria for N data points within the past M weeks may not be satisfied in an initial query, the user may decide to wildcard, for example, the exposure tool ID criteria to potentially allow further data points (i.e., satisfying the query regarding process system characteristics *other than* exposure tool ID). If N data points within M weeks are not retrieved after querying without employing exposure tool ID, the user may specify that the next process system criteria to be eliminated from the query may be reticle ID. Those of ordinary skill in the art will recognize this example as providing an illustration of the aforementioned hierarchical wildcarding, where query terms and/or correlation keys can be specified as employing an exact match (e.g., Windows 2000 operating system), a partial wildcard (e.g., a Windows operating system), or a complete wildcard (e.g., operating system not relevant).

As provided herein, the user can additionally and optionally establish a hierarchical rule for invoking the wildcards (e.g., in the example herein, exposure tool ID was ranked as the first parameter to wildcard, followed by reticle ID, etc.).

[0037] In some cases, the wildcarding process may not provide sufficient query results for allowing a computation of C_{FB} . In an embodiment, a user or another can be alerted or otherwise informed when C_{FB} cannot be computed because of insufficient query results, and such condition may require a manual adjustment to a system according to Figure 1.

[0038] As illustrated in Figure 1, some embodiments can allow a user or another to provide a manual input (e.g., user-specified input) to override or otherwise compensate the command vector, C_{FB} . Accordingly, a system based on the illustrated control system **30** can include one or more processor-controlled devices that can interface to the process system **12** and the measurement system **14**, where a user, system administrator, or another, referred to throughout herein collectively as a user, can access data at various stages of the control system **30** via a user interface (e.g., GUI, operating system prompt) and utilize one or more peripheral devices (e.g., memory, keyboard, stylus, speaker/voice, touchpad, etc.) to provide input or otherwise alter data at various stages of the control system **30**. A user can also utilize tools that can be incorporated into or otherwise interface with the control system **30** to analyze or otherwise view data at

1 various stages of the control system 30, where such analysis can be performed in real-time and/or
2 off-line. Accordingly, changes to the components of such a control system 30 can be performed
3 in real-time and/or off-line.

4 **[0039]** Those of ordinary skill in the art will recognize that in an example where the Figure 1
5 process system 12 can be a lithographic system and the measurement system 14 can be an
6 overlay measurement tool, the lithographic system 12 can be configured by a user to query for
7 data from the correlator module 26 and/or event database 28 to provide an initial command
8 vector, C_{FB} , where such query can also include or otherwise be based on process system
9 characteristics, hierarchical rules, wildcarding, and/or other criteria. Based on the filtered query
10 results, a C_{FB} can be provided for an initial wafer. If a C_{FB} cannot be computed based on a lack
11 of filtered query results, systems and methods according to Figure 1 may cause a “send-ahead”
12 wafer to allow processing and measurements upon which control can be provided. Using send-
13 ahead wafers and other such techniques can be costly and can adversely affect the throughput of
14 the methods and systems. As provided herein, to reduce the occurrences of ineffective queries
15 and hence “send-ahead” wafers, users may devise a query that wildcards enough process system
16 characteristics to obtain a desired number of query results to provide an initial C_{FB} , but such
17 wildcarding techniques can cause incompatible data (e.g., based on different process system
18 characteristics from that presently occurring in the process system 12) to be included in the C_{FB}
19 computation, and hence be ineffective in providing the desired control. For example, a user can
20 wildcard reticle ID, thus allowing the query to combine (e.g., compute a weighted moving
21 average) based on different reticle IDs. In this example, because different reticles have different
22 reticle errors, such errors remain uncompensated, and hence can combine in undesirable manners
23 to induce undesirable system performance, particularly when the process system 12 is presently
24 utilizing or otherwise affected by a specific reticle.

25 **[0040]** Figure 2 presents one illustrative system and method that can be based on and/or
26 otherwise incorporate features and/or concepts of Figure 1, and provides additional control for
27 systems and methods according to Figure 1, where the process system 12 can be a system that
28 can be affected by reticle-induced errors and/or includes a reticle, such as, for example, a

lithography and/or photolithography system. Systems and methods according to Figure 2 can be based on a consideration that photomask or reticle-induced errors can be considered static relative to other process system **12** errors that may be considered dynamic. Accordingly, systems and methods according to Figure 2 may allow a user to query the event database **28** based on hierarchical rules, wildcarding, etc., as provided previously herein with respect to Figure 1; however, when such query expands to collect data based on a complete and/or partial wildcard of reticle ID, such that a C_{FB} may be based on data from more than one reticle ID, a system according to Figure 2 can compensate such data by utilizing a reticle table **40** that can include reticle-induced error data based on reticle ID. As provided herein, the relative static nature of reticle-induced errors compared to other process system characteristics facilitates a compensation as provided in Figure 2. Systems and methods according to Figure 2 include a feedforward loop based on the reticle table **40** that allows reticle-induced errors to be deconvolved from dynamic errors of the process system **12** and/or measurement system **14**.

[0041] Those of ordinary skill in the art will thus recognize that when reticle ID is included as a correlation key (e.g., query item), system configurations that occur infrequently (“short-runners”) may provide inadequate query results, and hence cause a manual input to occur. Alternately, if the reticle ID is eliminated from the query (e.g., wildcarded), the combinations of frequent reticle changes in the process system **12** can cause a command/control vector C_{FB} that can cause uncontrolled disturbances (i.e., disturbances at frequencies greater than the process stream operating frequency) in the process system **12**.

[0042] The Figure 2 reticle table **40** can be a memory that associates at least one reticle ID to at least one reticle-induced error, reticle-induced bias, and/or reticle-induced offset, where the term “reticle-induced error” can be understood herein to include a reticle-induced bias, reticle-induced offset, or reticle-induced error, as such terms are known in the art, and where the association can be based on a process system **12** and/or a component of a process system **12**. In one embodiment shown in Figure 2, the reticle table **40** can accept reticle (e.g., photomask) error data from manually and/or automatically entered photomask measurements **42**, for example, that can be provided via an interface associated with the control system **30**. Such data may be

provided from a reticle manufacturer, for example, or from another test, manufacturing, and/or data collection facility. In an embodiment, the reticle table 40 can be updated automatically with data from a system according to Figure 2 system, as those of ordinary skill in the art will recognize that some components of, for example, E_g and/or I, may be associated with reticle-induced errors, and hence such data may be input to the reticle table 40 for updating reticle-induced errors.

[0043] Those of ordinary skill in the art will recognize that the reticle table 40 can also include additional data associations to enhance the data provided by the reticle table 40. Accordingly, processor instructions associated with the control system 30 can cause a query of the reticle table 40 where the query can also be specified by a user to allow hierarchical query terms, wildcard terms, etc., and accordingly, the reticle table can associate reticle-induced errors with, for example, layer IDs, device IDs, route IDs, operation IDs, and/or other process system 12 and/or measurement system 14 characteristics.

[0044] In one illustrative embodiment of a reticle table 40, for example, queries can be based on one or more reticle parameters that can include reticle ID, exposure tool ID, device ID, and layer ID. Generally, a reticle table 40 may associate these reticle parameters with one or more reticle-induced errors. As provided herein, those of ordinary skill in the art will recognize that “reticle-induced errors” can include errors in a process system that includes a reticle, can generally be associated with a reticle characteristic, and reticle-induced errors can be based on errors associated with reticle manufacture and/or errors associated with the interaction (e.g., alignment, loading) of a reticle with the process system 12 (e.g., exposure tool). For example, reticle-induced errors can include one or more of an x-translation error, a y-translation error, an x-scaling error, a y-scaling error, a wafer rotation error, a non-orthogonality error, a reticle magnification error, an asymmetric magnification error, a reticle rotation error, an asymmetry rotation error, a critical dimension (CD) linewidth bias, a dose bias, a reticle density, a mask density, a frame-to-frame alignment, a distance from optical center to frame center, an alignment mark line size, an alignment mark density, and an alignment mark duty cycle. Those of ordinary skill will recognize that some of the aforementioned reticle-induced errors may be duplicative

1 depending upon a given definition of an error, and accordingly, such errors are not intended for
2 limitation but for illustration of some reticle-induced errors that can be associated with reticle
3 characteristics and/or biases that can be associated with reticles in a process system 12. Some
4 embodiments may employ one or more of these errors and the number of errors associated with a
5 reticle ID can vary based on system characteristics (e.g., process system 12), reticle ID, and other
6 factors. As provided herein with reference particularly to Figure 3, the reticle table 40 can
7 include an association of reticle ID with a quality factor, and/or a use threshold, a stop-learning
8 threshold, and/or other criteria associated with a quality factor.

9 **[0045]** As Figure 2 indicates, the feed-forward correction, C_{FF} , can be, for example, based on
10 one or more reticle-induced error values (e.g., vector) from the reticle table 40 and can
11 compensate or otherwise factor into the C_{FFFB} that is computed as provided herein and described
12 relative to Figure 1, and thereafter employed as a basis for feedback and/or control to the process
13 system 12. According to Figure 2, such feed-forward correction, C_{FF} , can also be removed and/or
14 decoupled from the actual command or offset data to allow the I vector, referenced in Figures 1,
15 2, and/or 3, to be unaffected by the feed-forward correction.

16 **[0046]** The disclosed methods and systems can thus compute a control command for the
17 process system 12 based upon historical event database data, and compensate such control based
18 on reticle-induced errors when such historical data may be completely associated with the
19 process system's reticle (e.g., query provides sufficient data associated with the query-specified
20 reticle ID), partially associated with the process system's reticle (e.g., query provides data from
21 multiple reticles that include the query-specified reticle ID), and/or completely unassociated with
22 the process system's reticle (e.g., query provides data from one or more reticles, none of which
23 include the query-specified reticle ID).

24 **[0047]** Those of ordinary skill also recognize that the methods and systems exemplified by
25 the illustrations, including Figures 1, 2, and 3, are intended to facilitate an understanding of the
26 disclosed methods and systems, and thus, can be altered without affecting the scope of the
27 disclosed methods and systems. For example, results from a query of the event database 28 can
28 cause a query of the reticle table 40 such that reticle-induced errors can be extracted and a

command vector computed based on a weighted moving average of the event database data that can be adjusted based on the reticle table data. Accordingly, the reticle table 40 may be considered to be accessed by or otherwise included in the illustrated correlator module 26, and it can be understood that one or more databases can be employed to store at least A vectors, E_g vectors, and reticle-induced errors.

[0048] Further, those with ordinary skill will recognize other variations of the disclosed methods and systems. For example, in one embodiment, the process system 12 may provide process system data directly to the event database 12 (e.g., "A" vector data). Similarly, the measurement system 14 may also provide data directly to the event database 12. In an embodiment, an entry of measurement system data to the event database 12 can cause a computation of an error vector E_g as provided in the illustrated systems, where upon completion of the E_g computation, E_g can be associated with process system data (e.g., "A" vector data) in the event database 12. As provided herein, I data can thereafter be determined from the associated A vector data and E_g vector data. In some embodiments, such A and/or E_g data can also be associated with reticle-induced error data to facilitate the computation of C_{FFFB} as provided herein. Accordingly, and as provided herein, in some embodiments, the reticle table 40 can be incorporated, integrated, and/or otherwise associated with the event database 28.

[0049] Figure 3 presents one illustrative system and method that can be based on Figures 1 and/or 2 and provides additional control for systems and methods according to Figures 1 and/or 2, where the process system 12 can be a system that can be affected by reticle-induced errors and/or includes a reticle, such as, for example, a lithography and/or photolithography system. Systems and methods according to Figure 3 can be based on a consideration that photomask or reticle-induced errors can be considered static relative to other process system 12 errors that may be considered dynamic. Accordingly, systems and methods according to Figure 3 may allow a user to query an event database (not shown in Figure 3) or other similar data management system(s) based on hierarchical rules, wildcarding, etc., as provided previously herein with respect to Figures 1 and/or 2. The disclosed methods and systems thus allow for a computation

1 of a weighting measure of the feedback request, based at least on the number of events identified
2 by a feedback request and/or query.

3 **[0050]** In one embodiment, a weighting measure of the feedback can be based on, for
4 example, the “square root of N,” where N is the number of events retrieved based on the query.
5 It can be understood that other variations on the number of events can be used, and the
6 aforementioned weighting measure can be scaled and/or augmented by integer and/or non-integer
7 numbers. In one example embodiment, a weighting measure can be expressed as $10 \times (\text{square root of } N)$, although other scale factors can be used as previously provided herein. Such weighting
8 measure can be stored and/or otherwise associated with a query and/or reticle to which it is
9 associated, such that a history of queries and associated weighting measures can be subsequently
10 retrieved by a user. In one embodiment, such storage can be provided by an event database 28.
11 Furthermore, the disclosed methods and systems can allow for a computation of a weighting
12 measure for different levels of hierarchical queries, regardless of the number of events that may
13 be retrieved for the different levels.
14

15 **[0051]** In the disclosed methods and systems, weighting measures for feedback can be used
16 to compute a quality of a reticle bias state estimate. Accordingly, a reticle bias feedback quality
17 factor, referred to herein as “QF”, can be expressed as a combination of weighting measures
18 associated feedback requests that are further associated with a given reticle. For example, in
19 some embodiments, the weighting measures can be normalized based on the number of
20 weighting measures associated with a given reticle. Further, the QF or quality factor associated
21 with the reticle can be a combination of such normalized weighting measures. In one example
22 and as provided herein, the combination can include a square root of a sum of squares of
23 normalized weighting measures, although such combination is merely for illustrative purposes,
24 and other combinations can be employed without departing from the scope of the disclosed
25 methods and systems.

26 **[0052]** In one embodiment of the disclosed methods and systems, a user can input and/or
27 otherwise provide one or more data elements that can include a “use” criteria and/or threshold, a
28 “stop-learning” criteria and/or threshold, and/or other criteria that may be employed in assessing

1 a reticle bias state estimate based on a quality factor, QF. One such “other criteria” can be, for
2 example, determining that a quality factor for a given reticle bias state estimate may not be
3 updated unless a recently computed quality factor is a comparative improvement over one or
4 more prior quality factors associated with that same reticle. As an example, consider that on a
5 first day, a user query specifies a reticle A, a device ID, and a technology ID, but otherwise
6 wildcards other constraints and/or search keys. Also consider that on a second day, a user (same
7 or another) specifies only reticle A, but otherwise wildcards other constraints and/or search keys.
8 Both queries to the event database (e.g., see Figure 1 and/or 2) may include a different number
9 of query results depending upon the event database, and hence can provide a different weighting
10 measure and hence quality factor for an associated reticle bias state estimate. If a quality factor
11 associated with the estimate from the second day for reticle A, is comparatively improved from
12 the quality factor associated with the error estimate from the first day for that same reticle A, then
13 the reticle A bias error estimate and associated quality factor for the second day can be stored in a
14 database and/or memory (e.g., reticle table 40) and may be used (e.g., depending upon other
15 criteria) for feedback and/or feedforward. Alternatively, an opposite result may cause the reticle
16 A bias error estimate to fail to be updated based on the query of the second day.

17 **[0053]** As provided previously herein, other criteria and/or thresholds that can be used may
18 include a use threshold and a stop-learning threshold. It can be understood that the use of “use”
19 and “stop-learning” is merely for reference purposes, and other names can be employed without
20 departing from the scope of the disclosed methods and systems. In the example embodiments
21 provided herein, a “use” threshold can be associated with a user-specified and/or provided
22 criteria such that, when a quality factor associated with a reticle bias state estimate exceeds
23 (and/or equals) the use threshold, the associated reticle bias state estimate can be employed in a
24 feedforward/feedback system as provided in Figures 1, 2, and/or 3, for example. Alternately and
25 similarly, if a quality factor is less than the use threshold, such associated reticle bias state
26 estimate may not be employed in the feedforward/feedback request; however, the reticle bias
27 state estimate data and associated quality factor may be entered into a database regardless,

providing that other criteria are satisfied (e.g., the most recently computed quality factor exceeds a prior computed quality factor).

[0054] A “stop-learning” threshold can be employed to prevent a reticle bias state estimate from being updated when a quality factor associated with a given reticle and query produces a quality factor that is equal to or exceeds a stop-learning threshold. In an embodiment where a stop-learning threshold exceeds the use threshold, and a data query provides a reticle bias state estimate with an associated quality factor that exceeds both thresholds, the disclosed methods and systems may employ the stored reticle bias state estimate, and fail to do further updating of the reticle bias state estimate. The optional and example stop-learning threshold can thus be understood to be a constraint on updating of stored reticle bias state data, rather than a constraint on use of the stored reticle bias state data.

[0055] For an embodiment of the disclosed methods and systems that employs a use and a stop-learning threshold as provided herein, and further, a tiered and/or hierarchical querying methodology, as provided previously herein, a weighting measure can be computed for the different levels/tiers, such that the different weighting measures can be compared and the largest weighting measure employed to identify a query that may be used to compute an updated reticle bias state estimate, including for example, an updated quality factor associated with such updated reticle bias estimate. As provided herein, whether a database is updated based on the selected and/or identified query can be based on whether such newly computed/updated quality factor exceeds an associated stop-learning threshold; and, whether the reticle bias state estimate is employed to satisfy the feedback request can be governed by an associated use threshold.

[0056] Figure 4 provides one flow diagram **400** of a system and method for providing a reticle bias state for systems and methods that employ both a use threshold and a stop learning threshold. As Figure 4 indicates, a query such as a hierarchical query can be executed **402** to provide data from an event database, for example, for one or more queries that can be presented in a hierarchical format. For systems and methods according to Figure 3, it may be understood that the query must include a specified reticle ID, overlay process model ID, and/or CD process model ID (i.e., such parameters may not be “wildcarded”), while other parameters such as

exposure tool ID, device ID, technology ID, layer ID, route ID, and operator ID, can be allowed to have default and/or wildcard values.

[0057] In one embodiment, the query results can be presented to a filter, such as a band-pass filter, that receive as input modeled historical data for certain modeled terms in a query (e.g., x-translation error, y-translation error, etc.). An example filter can be of the form of $(\text{filter mean}) + k(\text{filter sigma})$, and the constant “k” can be fixed, variable (e.g., adaptable), and/or user-defined. Accordingly, query response data not within the pass-band of the filter may not be provided for further computation, etc.

[0058] The results of the different queries can be provided to a module to compute a weighting measure based on the different query results 404. Based on the one or more computed weighting measures, a largest (or other selected) weighting measure can be determined 404 and a reticle bias state estimate updated based thereon, with a corresponding computation of a quality factor to be associated with the updated reticle bias state estimate 406. If the QF associated with the updated reticle bias state estimate is not greater than a QF for a prior reticle bias state estimate (e.g., of the database) 408, then the disclosed methods and systems can determine whether the prior, stored reticle bias state estimate is greater than the use threshold 410; and, if the stored reticle bias state estimate is greater than the use threshold, the feedback request may provide the stored reticle bias state estimate 422 to the process system 12. Alternately, if the stored QF is not greater than the use threshold at 410, then the disclosed embodiment may not update the database or provide a feedback that contains a reticle bias state estimate 412.

[0059] With continued reference to Figure 4, and the decision shown at 408, if the computed QF is greater than the QF for a prior (e.g., stored) reticle bias state estimate, then such computed reticle bias state estimate QF can be compared to the use threshold associated with the reticle 414, and if the computed QF is not greater than the use threshold, such computed QF and associate reticle bias state estimate can be stored and associated with data for the reticle 416. Such data can be stored in a database and/or other memory structure 416, and such database can associate the reticle (e.g., identifier), quality factor (QF), error vector data (e.g., “E” vector data), process system data (e.g., “A” vector data), and other data. Returning again to the decision at

414, if the computed QF is greater than or equal to the use threshold for the given reticle, then the computed QF can be compared to the stop-learning threshold 418. If the computed QF is greater than the stop-learning threshold for the given reticle, then in the Figure 4 embodiment, the reticle bias state estimate stored in the database 422 can be employed in the feedback request; alternately, the database can be updated 420 (e.g., with the reticle bias state estimate, associated QF, and/or other data) and the updated reticle bias state estimate can be employed in the feedback request 422. As provided previously herein, it can be understood that the elements of Figure 4 can be rearranged, combined, and/or further separated without departing from the scope of the disclosed methods and systems.

[0060] In one embodiment, such as the embodiment shown in Figure 3, computation of the reticle bias state estimate and other quantities can be based on the process system data (e.g., A vector data). For example, as provided with reference to Figures 1 and 2, and with continued reference to Figure 3, process system data can be stored in an A-vector database and/or table 302. It can be understood that subscripts of (i-1, i-n) in Figure 3 can refer to values i-1 to i-n that may be employed for feedback for the ith lot of a process for different reticles, for example, where n is the total number of feedback lots. Further subscripts of (j-1, j-n) in Figure 3 can refer to values j-1 to j-n, where j is the historical feedback data pertaining to a given reticle.

[0061] As shown in Figure 3, error data can be stored in a database and/or table 304 and can be differentiated based on a given reticle such that error data for different reticles, $E_{(i-1, i-n)}$ can be distinguished from error data for a given reticle, $E_{(j-1, j-n)}$, for which the feedback request corresponds. Input bias tables 48 and gain tables 22 can be accessed to provide data, via setpoint methods 306a-b and gain methods 308a-b, respectively, to provide bias and gains to the respective error vectors, $E_{(i-1, i-n)}$ and $E_{(j-1, j-n)}$. The set point bias data 48 can also be known or referred to as an input bias and can control the process system 12 to regulate to a non-zero value. In a photolithography embodiment, an input/set point bias could compensate for a known etch process bias, for example. The error vector data pertaining to the given reticle, $E_{G(j-1, j-n)}$ can be provided to a reticle learning module 310 that can perform the following computations:

$$[0062] \quad A_r = C_{r(j-1, j-n)} + (A_{(j-1, j-n)} - C_{FFFB(j-1, j-n)}), \quad (1)$$

where:

A_r is corrected process system data for the given reticle;

$C_{r(j-1, j-n)}$ is the reticle correction factor for the given reticle;

$A_{(j-1, j-n)}$ is the process system data related to the given reticle; and,

$C_{FFFB(j-1, j-n)}$ is the feed forward, feedback control for the given reticle.

[0063] Further, the reticle learning module 310 can compute an “I” vector by differencing the corrected process system data, A_r , and the error vector data for the given reticle, $E_{G(j-1, j-n)}$, or,

[0064]
$$I_r = A_r - E_{G(j-1, j-n)}. \quad (2)$$

[0065] The reticle bias state estimate can thereafter be computed according to:

[0066]
$$B_r = W_i I_r / \text{Sum}(W_i),$$

(3)

where:

W_i are the normalized weighting measures for different feedback requests,

where W_i can be expressed as $Q_i / \text{SUM}(Q_i \dots Q_n)$, and Q_i can be

expressed as the aforementioned weighting measures (e.g.,

$10 * \text{sqrt}(N)$);

N is the number of I_r vectors.

[0067] A quality factor, QF , associated with B_r can thus be expressed as:

$$QF = \text{sqrt}(Q_1^2 + Q_2^2 \dots + Q_n^2) \quad (4)$$

[0068] As provided with respect to Figure 4, for example, such quality factor can be compared to other factors previously computed for the same reticle (e.g., which may be stored in the reticle bias table 310), use threshold, stop learning threshold, and/or other criteria as previously provided herein.

[0069] It can be understood that in some embodiments, a use, stop-learning, and/or other criteria can be specified by a user and applied against different reticles/reticle IDs, while in some embodiments, different reticles can be associated with different use, stop-learning, and/or other criteria. Furthermore, in some embodiments, a user can set and/or reset a quality factor, QF ,

1 associated with a reticle via a user interface or other mechanism, and such setting and/or resetting
2 can be accomplished upon and/or after initialization of systems and methods according to Figures
3 1, 2, and/or 3. In some embodiments, for example, setting a quality factor for a given reticle to
4 zero may indicate that the state of the reticle bias state estimate is unknown. It can be understood
5 that in some instances, a user or another may wish to set the (stored, database) quality factor for a
6 given reticle to a use threshold so that “learning” can continue, however, because the stored
7 quality factor equals the use threshold, the stored reticle bias state estimate can be used.

8 **[0070]** Referring again to Figure 3, the illustrated system and method can include an output
9 bias **44** that can also be known as a feed-forward bias, and in a lithography process system **12**
10 that includes an exposure tool, such bias can represent a bias to compensate a bias produced by a
11 known characteristic of the material entering the process system **12**, where the process system **12**
12 can be, for example, an exposure tool. In an illustrative system, if the mean thickness of the
13 nitride layer for a particular group of wafers has been measured, a bias can be provided to
14 compensate for the thickness difference.

15 **[0071]** As shown by Figure 3, the illustrated methods shown as **306a-b**, **308a-b**, **312** can be
16 understood to be processes such as queries for extracting from a respective database and/or
17 memory, data sufficient to aid in the processing as provided by Figure 3. As provided previously
18 herein with respect to other Figures, one of ordinary skill in the art can recognize that the
19 components of Figure 3 are merely illustrative, and can be otherwise combined, rearranged,
20 and/or further separated, in whole or in part, without departing from the scope of the disclosed
21 methods and systems.

22 **[0072]** What has thus been described are systems and methods that include methods and
23 systems for estimating a reticle bias state for a process system, that include computing a
24 difference between control data provided to the process system and error data based on at least
25 one output of the process system, and estimating the reticle bias state based on weighted
26 measures associated with the control data, where the weighted measures are based on the number
27 of data points included in the difference. The methods and systems also include associating a
28 reticle bias state estimate with a first quality factor, computing at least one weighted measure

1 based on a number of data elements associated with the reticle, using the at least one weighted
2 measure to provide a computed reticle bias state estimate and an associated computed quality
3 factor, and, comparing the computed quality factor with the first quality factor to determine
4 whether to update the reticle bias state estimate with the computed reticle bias state estimate.

5 **[0073]** The methods and systems described herein are not limited to a particular hardware or
6 software configuration, and may find applicability in many computing or processing
7 environments. The methods and systems can be implemented in hardware or software, or a
8 combination of hardware and software. The methods and systems can be implemented in one or
9 more computer programs, where a computer program can be understood to include one or more
10 processor executable instructions. The computer program(s) can execute on one or more
11 programmable processors, and can be stored on one or more storage medium readable by the
12 processor (including volatile and non-volatile memory and/or storage elements), one or more
13 input devices, and/or one or more output devices. The processor thus can access one or more
14 input devices to obtain input data, and can access one or more output devices to communicate
15 output data. The input and/or output devices can include one or more of the following: Random
16 Access Memory (RAM), Redundant Array of Independent Disks (RAID), floppy drive, CD,
17 DVD, magnetic disk, internal hard drive, external hard drive, memory stick, or other storage
18 device capable of being accessed by a processor as provided herein, where such aforementioned
19 examples are not exhaustive, and are for illustration and not limitation.

20 **[0074]** The computer program(s) can be implemented using one or more high level
21 procedural or object-oriented programming languages to communicate with a computer system;
22 however, the program(s) can be implemented in assembly or machine language, if desired. The
23 language can be compiled or interpreted.

24 **[0075]** As provided herein, the processor(s) can thus be embedded in one or more devices
25 that can be operated independently or together in a networked environment, where the network
26 can include, for example, a Local Area Network (LAN), wide area network (WAN), and/or can
27 include an intranet and/or the internet and/or another network. The network(s) can be wired or
28 wireless or a combination thereof and can use one or more communications protocols to facilitate

communications between the different processors. The processors can be configured for distributed processing and can utilize, in some embodiments, a client-server model as needed. Accordingly, the methods and systems can utilize multiple processors and/or processor devices, and the processor instructions can be divided amongst such single or multiple processor/devices.

[0076] The device(s) or computer systems that integrate with the processor(s) can include, for example, a personal computer(s), workstation (e.g., Sun, HP), personal digital assistant (PDA), handheld device such as cellular telephone, laptop, handheld, or another device capable of being integrated with a processor(s) that can operate as provided herein. Accordingly, the devices provided herein are not exhaustive and are provided for illustration and not limitation.

[0077] References to “a microprocessor” and “a processor”, or “the microprocessor” and “the processor,” can be understood to include one or more microprocessors that can communicate in a stand-alone and/or a distributed environment(s), and can thus can be configured to communicate via wired or wireless communications with other processors, where such one or more processor can be configured to operate on one or more processor-controlled devices that can be similar or different devices. Use of such “microprocessor” or “processor” terminology can thus also be understood to include a central processing unit, an arithmetic logic unit, an application-specific integrated circuit (IC), and/or a task engine, with such examples provided for illustration and not limitation.

[0078] Furthermore, references to memory, unless otherwise specified, can include one or more processor-readable and accessible memory elements and/or components that can be internal to the processor-controlled device, external to the processor-controlled device, and/or can be accessed via a wired or wireless network using a variety of communications protocols, and unless otherwise specified, can be arranged to include a combination of external and internal memory devices, where such memory can be contiguous and/or partitioned based on the application. Accordingly, references to a database can be understood to include one or more memory associations, where such references can include commercially available database products (e.g., SQL, Informix, Oracle) and also proprietary databases, and may also include other structures for

1 associating memory such as links, queues, graphs, trees, with such structures provided for
2 illustration and not limitation.

3 **[0079]** References to a network, unless provided otherwise, can include one or more intranets
4 and/or the internet. References herein to microprocessor instructions or microprocessor-
5 executable instructions, in accordance with the above, can be understood to include
6 programmable hardware.

7 **[0080]** Unless otherwise stated, use of the word “substantially” can be construed to include a
8 precise relationship, condition, arrangement, orientation, and/or other characteristic, and
9 deviations thereof as understood by one of ordinary skill in the art, to the extent that such
10 deviations do not materially affect the disclosed methods and systems.

11 **[0081]** Throughout the entirety of the present disclosure, use of the articles “a” or “an” to
12 modify a noun can be understood to be used for convenience and to include one, or more than
13 one of the modified noun, unless otherwise specifically stated.

14 **[0082]** Elements, components, modules, and/or parts thereof that are described and/or
15 otherwise portrayed through the figures to communicate with, be associated with, and/or be
16 based on, something else, can be understood to so communicate, be associated with, and or be
17 based on in a direct and/or indirect manner, unless otherwise stipulated herein.

18 **[0083]** Although the methods and systems have been described relative to a specific
19 embodiment thereof, they are not so limited. Obviously many modifications and variations may
20 become apparent in light of the above teachings. For example, some embodiments may use
21 pattern density, otherwise known as photomask density, in a feedforward in an etch or CMP
22 process.

23 **[0084]** Many additional changes in the details, materials, and arrangement of parts, herein
24 described and illustrated, can be made by those skilled in the art. Accordingly, it will be
25 understood that the following claims are not to be limited to the embodiments disclosed herein,
26 can include practices otherwise than specifically described, and are to be interpreted as broadly as
27 allowed under the law.